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METEOROID PROTECTION FOR SPACECRAFT STRUCTURES

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The objective of this program is to determine, within the limits of present knowledge of the meteoroid environment and laboratory simulation capability, the materials, thicknesses, and geometric characteristics of meteoroid barriers.

The significance of the meteoroid hazard can best be placed in perspective by applying presently available data and shielding concepts to a specific vehicle. Using a cryogenic propulsion module as an example, the following tasks must be performed:

1. Preliminary design to meet a specific set of operational requirements and to obtain minimum gages, spatial relationships and other design constraints.
2. Development of shielding concepts and requirements using available data and additional support from an experimental program. Materials, insulations and gages must be related to actual hardware, with emphasis on integration of structural, thermal and meteoroid provisions to obtain minimum weight and maximum operational capability. Correlation of data must consider the need to extrapolate from the Laboratory test points to the meteoroid design region.
3. Application of available and generated data on meteoroid barrier concepts to the preliminary design of a cryogenic spacecraft propulsion module.

<u>Propulsion Module Design</u>

Preliminary design studies of the cryogenic module have been completed. A module with cylindrical tanks and elliptical heads (one hydrogen tank and four oxygen tanks) was selected because it offered the advantage of maximum meteoroid shield envelope flexibility in addition to ease of manufacture and reasonable structural weight. The module weight and length were determined using several depths of meteoroid shielding. The results are presented in Fig. 1. These curves were prepared on the assumption of using a three layered structural system of 7075-T6 aluminum with the same sheet thickness employed for all shield depths.

Studies utilizing available information on meteoroid penetration were made on several types of compression structure. The combinations considered were:

1. Integral milled and bonded skin stringer combinations
2. Integral milled waffle panels
3. Honeycomb sandwich panels
4. Corrugated core compression sandwich panels

In each case a three layered structure was considered. The two inner sheets were used as a combination shield and compression structure while the outer sheet was a nonstructural shield. The materials considered included 2000 and 7000 series aluminum, magnesium lithium (LA 141), 300 series stainless steel and 6Al-4V titanium. Table 1 compares the relative weights of several types of uniformly loaded compression structure utilizing the lightest materials for this application, aluminum and magnesium-lithium. The results indicate that the lightest structure for areas that are relatively cool and have light uniform loads is a bonded or extruded magnesium-lithium skin-stringer sandwich with a magnesium-lithium shield.

For areas with relatively high concentrated attachment loads the lowest weight configuration is an extruded and machined integral skin-stringer panel made of 7075-T6 aluminum with a second 7075-T6 sheet bonded to the top of the stringers and with a magnesium-lithium shield.

The studies indicate that areas exposed to exhaust-plume heating are best served by two sheets of 7075-T6 aluminum and a 321 stainless steel bumper plate joined with a minimum of angles and clips.

Two configurations of the propulsion module meteoroid barrier and structural support systems have been prepared. Both configurations are based on a three-layered barrier system with a corrugated magnesium-lithium (LA-141) outer shield and a two-layered compression structure sandwich. The compression structure consists of an extruded skin stringer panel with a second sheet bonded to the tops of the stringers. The basic difference between the two shield systems is in the material selected for the compression structure. One utilizes 7075-T6 aluminum, while the other uses magnesium-lithium. The use of magnesium-lithium saves weight (300 to 500 pounds) but requires development in bonding and extruding of large panels. Preliminary work on bonding and extruding small parts by industry has shown promise.

A low density filler material is attached between the sheets of the compression structure; testing has not progressed to the point where a designation can be made of this material. The purpose of the filler is to reduce overall shield system weight by slowing or stopping fragmented particles.

On the basis of data generated for Saturn, aerodynamic heating rates on the outer surface are estimated to be sufficiently low, so that an .040 magnesium-lithium sheet will be adequate when coated with high emissivity paint. An outer shield panel of 19 x 35 inches was selected by panel flutter and acoustic noise considerations.

The support system selected for the single hydrogen tank is shown in Figure 2. In this concept, the attachment is made by a cone structure between module-attach ring and the thin outer tank-skin.

The inner tank and liquid hydrogen weight is transmitted to the thin outer-skin by compressing the insulation. A sliding support on the lower end permits longitudinal shrinkage of the outer shell and also carries part of the side load.

Two other support methods considered were direct point attachment of the thin outer-tank to the propulsion module compression structure, and direct attachment of the inner tank to the compression structre. The first approach was rejected because of acoustic noise considerations, the second because of high heat leak.

Several methods for supporting the four liquid oxygen tanks between the members of the engine-attach cross beams were considered. One method required attachment to the outer shell,(Figure 3).

In this scheme the weight of the inner tank and oxygen is transmitted to the outer shell by means of the compressed insulation. Loads are transmitted from the outer shell to the cross-beams by a short beam structure. Another possibility for load transfer from the outer shell is by means of a net fastened around the soft outer shell and attached to the cross-beams. The problem of maintaining tension under varying temperature and load conditions may require using a mechanical means of adjusting tension. A third possibility is to tie directly to the inner tank, using either a titanium or a fiberglass beam (Figure 4).

In evaluating these approaches, the considerations were weight, development and fabrication problems, and liquid oxygen loss from support sypstem heat leak. These considerations are summarized in the following table:

	Type Support	Liquid O_2 Loss Thru Support System	Frame Weight Requirement	Remarks
1	Tie to Frame on outer tank	less than 5 lbs	Yes (outer tank)	
2	Net support on outer tank	less than 5 lbs	No	Development problem of maintaining tension in nets
3	Titanium support to inner tank	70 lbs	Yes (inner tank)	
4	Fiberglass support to inner tank	105 lbs	Yes (inner tank)	

Comparison of methods 3 and 4 shows that the titanium beam, which has a smaller cross-section, is lighter and causes less liquid O_2 loss than the larger fiber glass beam.

Of the methods investigated, it appears that the only one not requiring a frame is the net-type of support for the outer tank. However, development of mechanical means to maintain correct tension in the nets is required. The most promising method appears to be a tie to a frame on the outer tank. The weight penalty is equal to that of the inner tank attachment, but the 70 to 100 pound loss of liquid oxygen is avoided.

The preliminary work on the module is complete, except for making changes dictated by the test program. It is planned to make these changes after the majority of testing is complete.

Material Evaluation

A comprehenvsive experimental study of bumper and filler materials has been planned and testing is under way. It is believed that greater understanding of the penetration process will be obtained under this program by studying the efficiencies of the various shield and filler materials separately prior to testing them in combination. It is felt that this portion of the testing can best be accomplished using the Boeing 1/32" and 1/16" light gas guns.

The filler materials which are currently being tested include:

1. Polyurethane
2. Polystyrene (rigid, in 3 density ranges)
3. Q-felt
4. Stabilized Q-felt (compressed and rigidized)
5. Dexiglas
6. Owens-Corning TWF Insulating wool

These materials have been tested using 1/32" projectiles in the medium velocity range (14,000 to 20,000 ft/ sec) in an attempt to evaluate their efficiency in defeating particles of this size.

Some trends have become apparent based upon the testing done so far:

1) Fiberous filler materials (Glasswool and Q-felt) are more effective than celluluar materials (Polystyrene and polyurethane) in eroding projectile fragments.

2) No weight advantage appears to be gained by increasing the density of the rigid cellular fillers. For example, if the three densities of polystyrene foam are compared on a "weight per unit area" basis, (weight per unit area = depth of penetration x weight/unit volume) the quantity of material required to defeat a 0.49 mg magnesium-lithium particle at approximately 16,000 ft/sec is 0.110 $\pm$ 0.010 lbs/ft^2 for all densities. Similar tests using 1.02 mg aluminum particles at approximately 15,000 ft/sec show that 0.200 $\pm$ 0.030 lbs/ft^2 are needed.

3) Multiple close packed layers of foil and insulation materials such as Dexiglas do not appear promising as barrier elements. It is estimated that 17.6#/ft^2 is required to defeat a 1.02 mg aluminum particle at

approximately 18,000 ft/sec.

Barrier geometry testing has been initiated utilizing the 1/4 inch light gas gun. The purpose of this series of tests is to investigate the effects of shield thickness and spacing. The materials used were 2024-T3 aluminum sheet and Owens Corning TW-F insulating wool. All tests were performed with 1/4 inch spherical aluminum projectiles in the 20,000 ft/sec range.

The insulating glass wool was chosen as filler material because althought it was not the lightest material it had other desirable characteristics. Insulating wool is readily compressible and allows a wide range of densities to be obtained easily. Unlike the cellular materials, it permits the products of the explosive reaction during impact to be vented thus minimizing the volume of damaged filler. Finally the glass-wool and also Q-felt are relatively inert and contribute fewer volatile products to the reaction.

Some typical configurations used to determine the effects of geometry and subsequent damage are shown in Figure 5. Photographs of specimens are shown in Figures 6 through 13.

Based upon testing done to date the following trends have been observed:

(1) Closed cell foams are undesirable. The outer shield shatters the projectile into many small particles some of which are vaporized (along with the filler material) giving rise to an expanding volume of gas. Closed cell foams tend to trap gas in the cells which then increases the explosive character of the reaction. The resulting pressure pulse shatters the filler material over a wide area adjacent to the path of the particles and substantially increases the damage to the inner shield. The skin suffers a large petal-shaped hole similar to those frequently seen when explosions occur adjacent to thin sheet structures.

A similar effect is observed for any low density filler if sufficient space is not provided between the shield and the skin to ameliorate the effects of the explosive reaction (see figure 13)

2) From a weight standpoint the most efficient configuration appears to be a three-sheet sandwich with filler material adjacent to the outer shield. A plausible explanation is that the two outer shields and filler, shatter and erode the projectile while the intervening space in front of the inner skin allows the pressure pulse to dissipate before striking the skin.

Shield Material Evaluation

Several tests were performed to determine the effect of projectile density. The configurations used were 0.008" and 0.010" Rene'41 sheet placed 1/2" in front of aluminum witness plates. The projectiles were 1/32" cylinders of aluminum and magnesium-lithium. In each test the diameter of the hole caused by the less dense magnesium-lithium projectile was approximately 75% of that caused by the aluminum. The associated damage to the witness plate was also considerably less. Microscopic examination of the holes in the bumper and the craters in the witness plate indicate that the appearance of damage is identical to that from large projectiles impacting thick shields and semi-infinite targets. (This fact lends support to the thesis that a large amount of screening of materials can be successfully accomplished using miniaturized equipment).

Several tests utilizing aluminum shields of various thicknesses were also performed. The gages varied from 0.003" to 0.040. The data collected are as yet insufficient to warrant any conclusions.

Outside Facility Review

In an attempt to establish the velocity-mass capability of other facilities, requests for quotation were sent to ten industrial and educational research organizations.

These facilities were selected on the basis of reputation and published information indicating that their equipment could meet mass and velocity requirements. To date nine replies have been received.

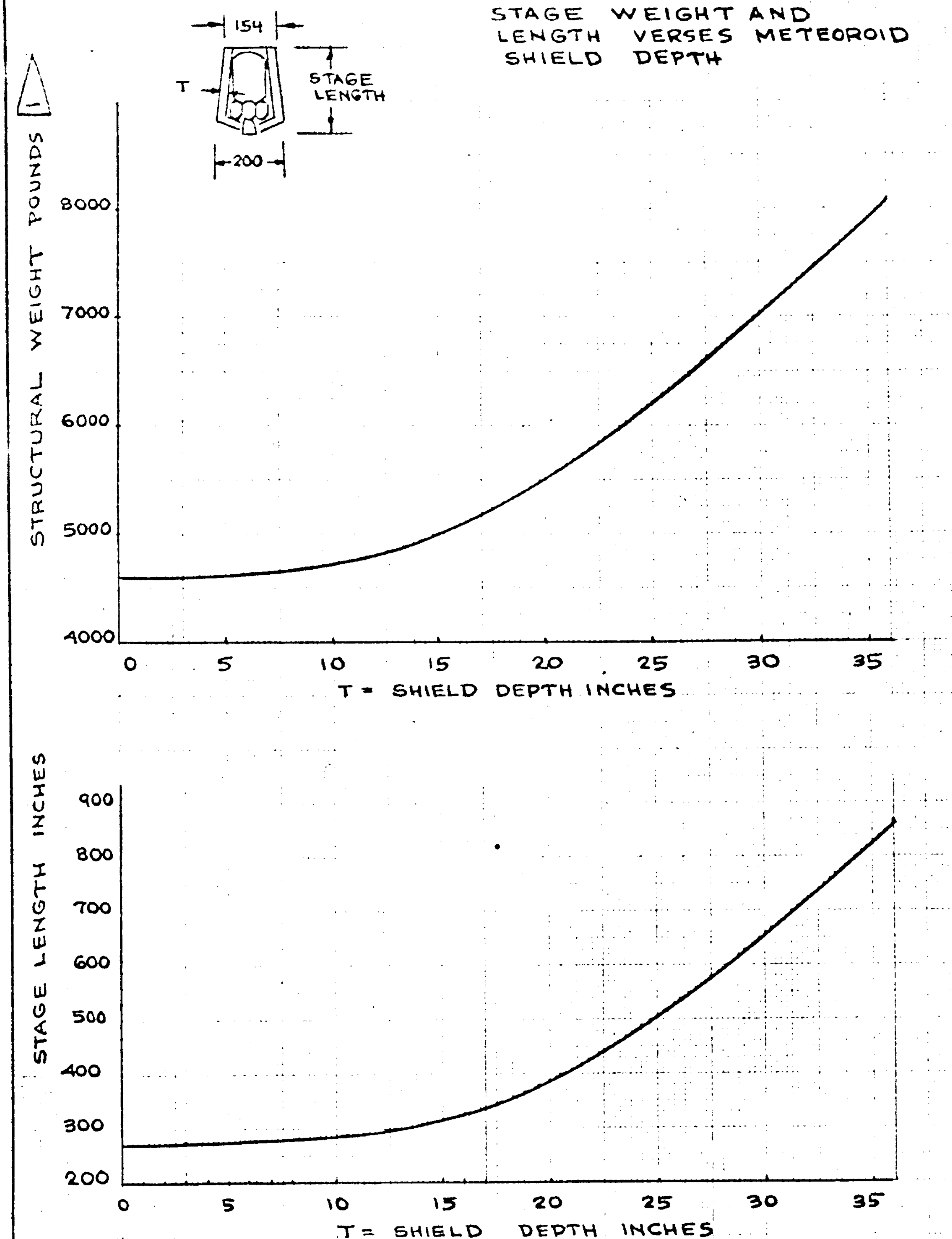
The work planned for the forthcoming period includes:

1) Evaluation of outside facilities
2) Evaluation of filler materials at higher velocities
3) Evaluation of shield materials and thicknesses at velocities above 24,000 ft/sec
4) Barrier geometry testing

No problems have arisen that will affect the completion of this program.

J. F. Lundeberg

STAGE WEIGHT AND LENGTH VERSES METEOROID SHIELD DEPTH



1 INCLUDES WEIGHT OF TANK + INSULATION, ATTACH STRUCT, SHIELD + COMPRESS. STRUCT

CALC	W HAESE	8-15-3	REVISED	DATE	STAGE WEIGHT AND LENGTH VERSES METEOROID SHIELD DEPTH	
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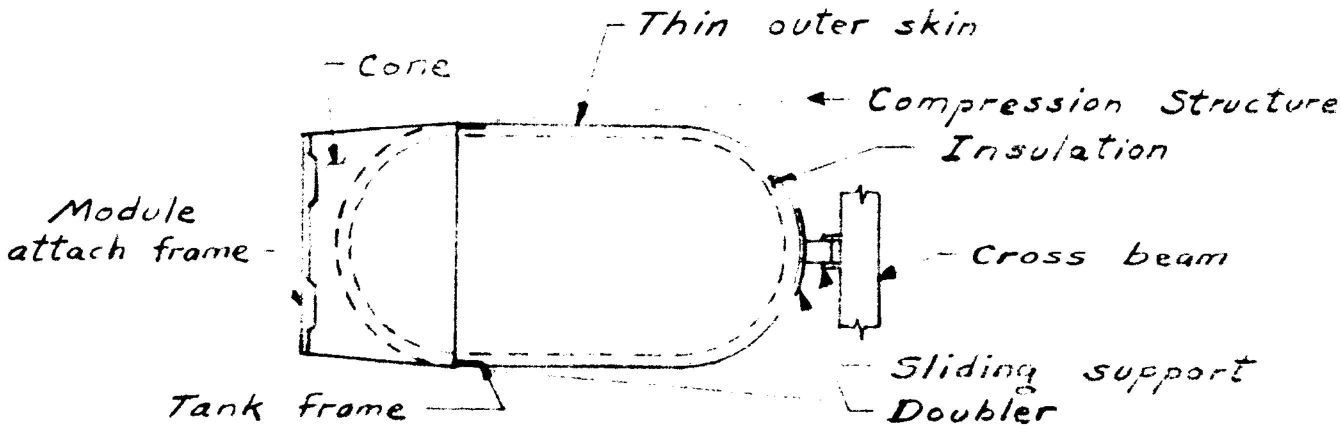


FIGURE 2

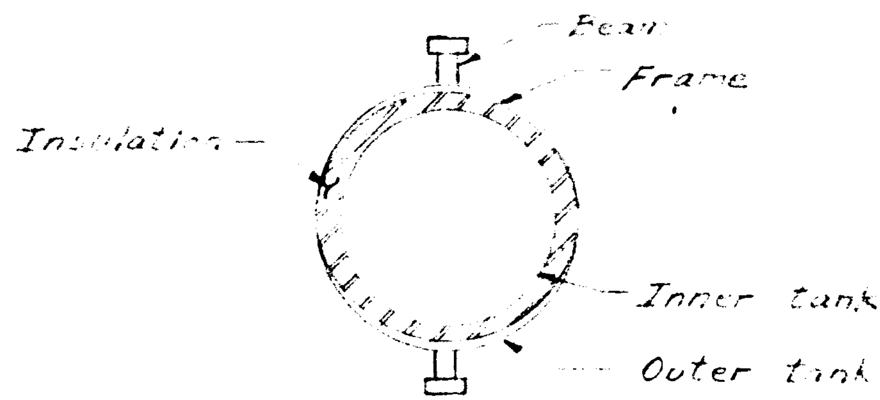


FIGURE 3

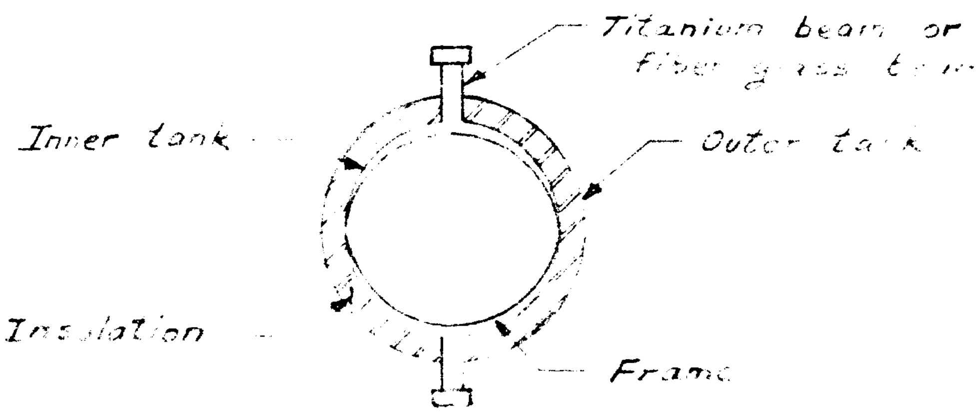


FIGURE 4

TYPICAL CONFIGURATIONS

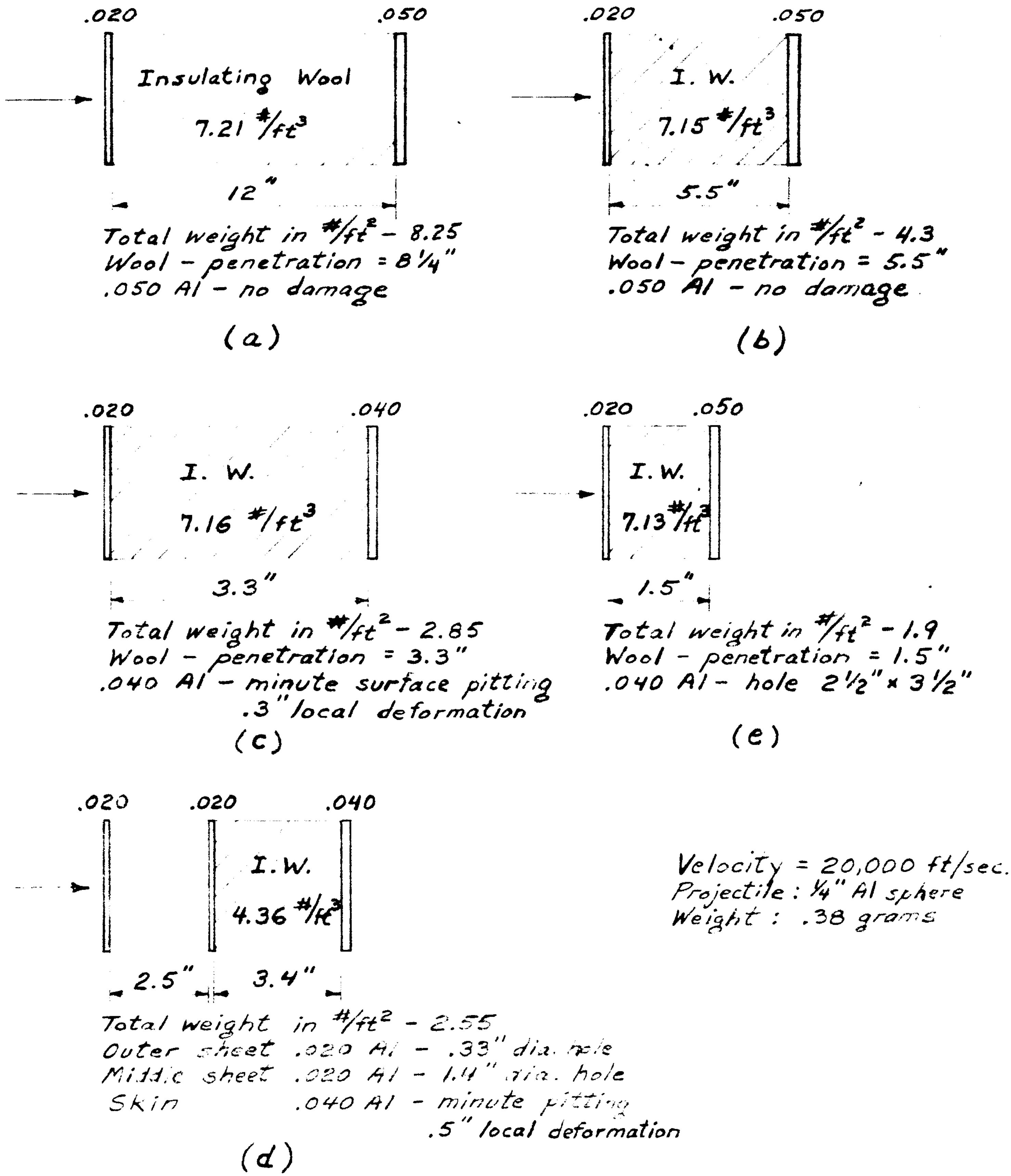
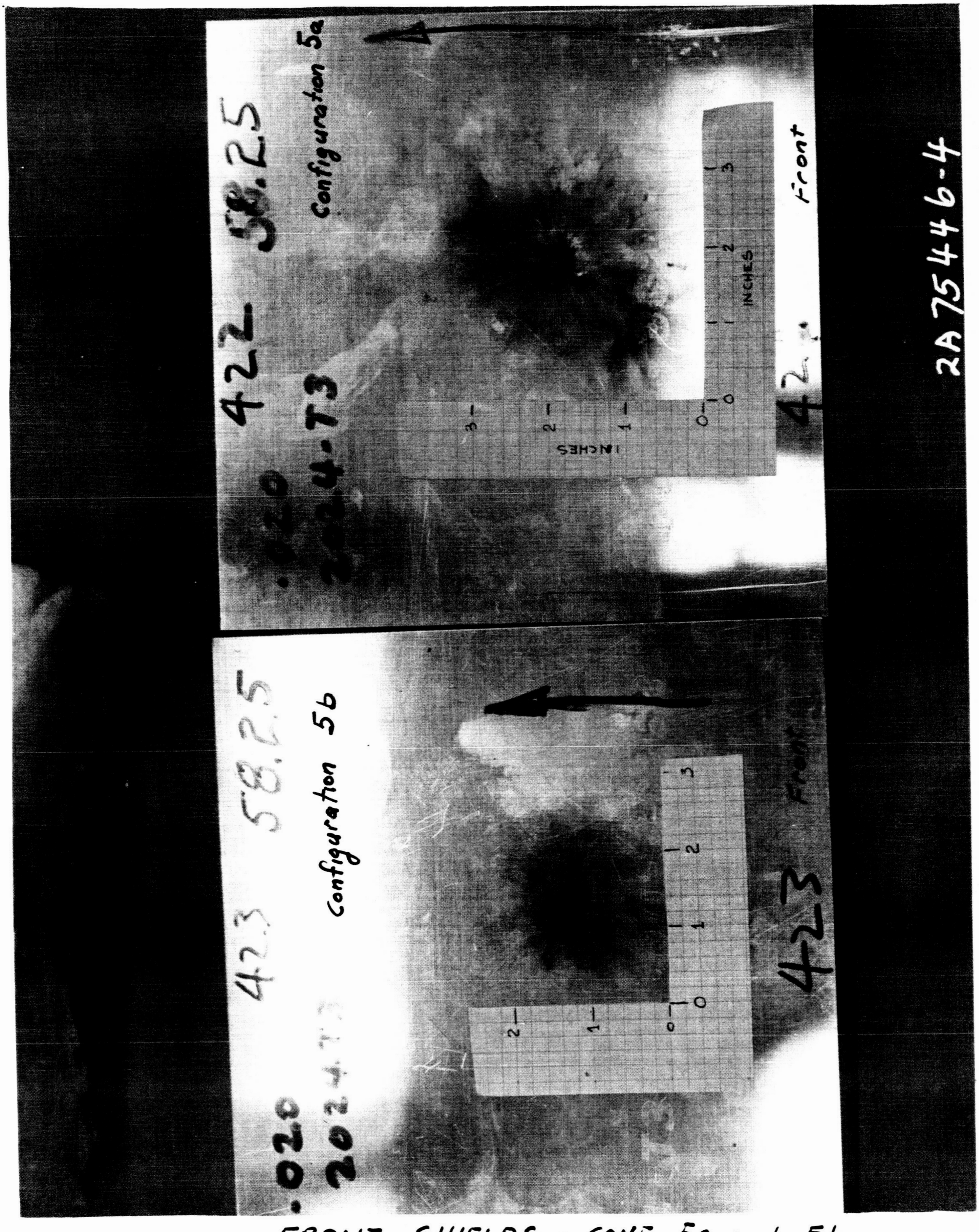
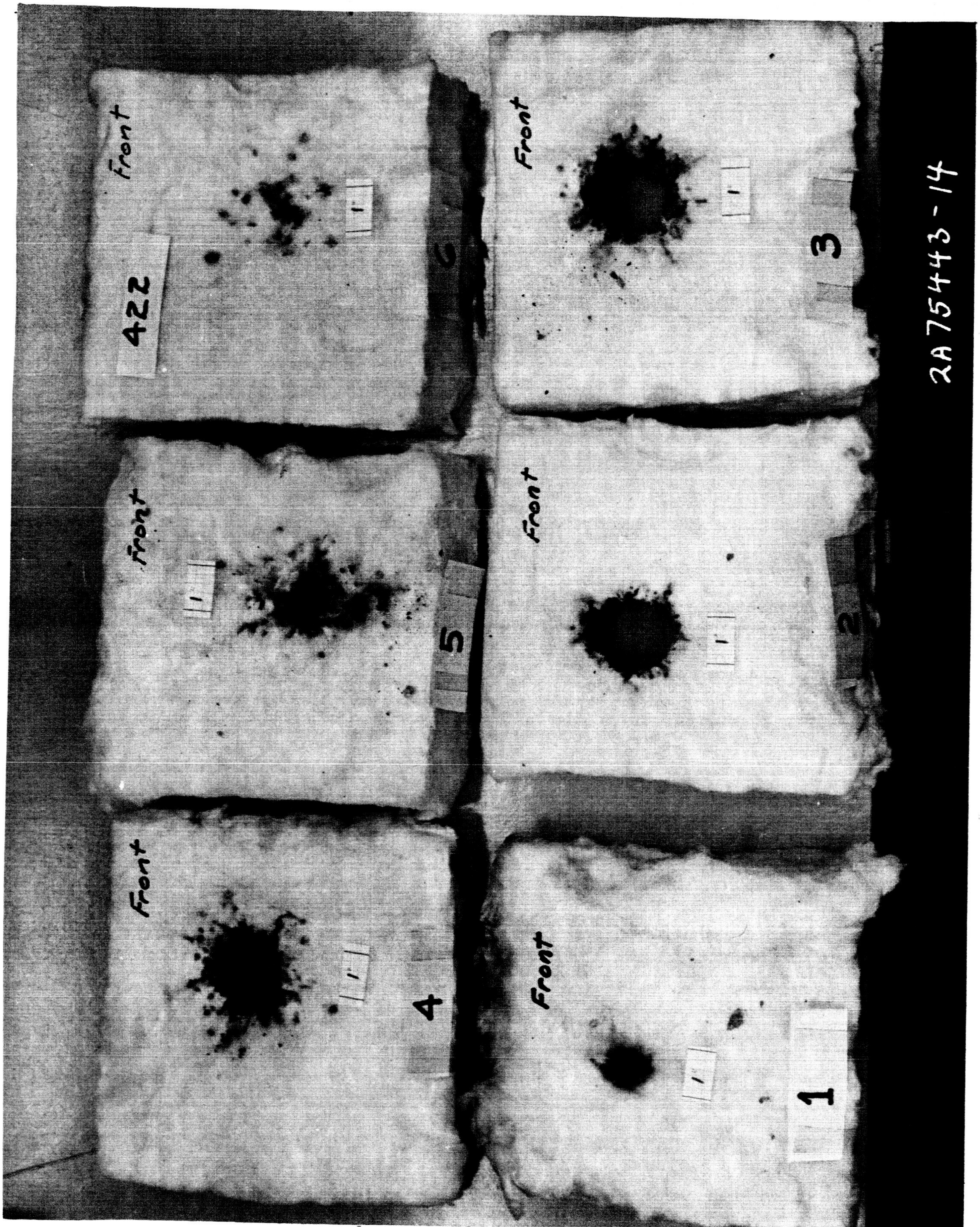


FIGURE 5



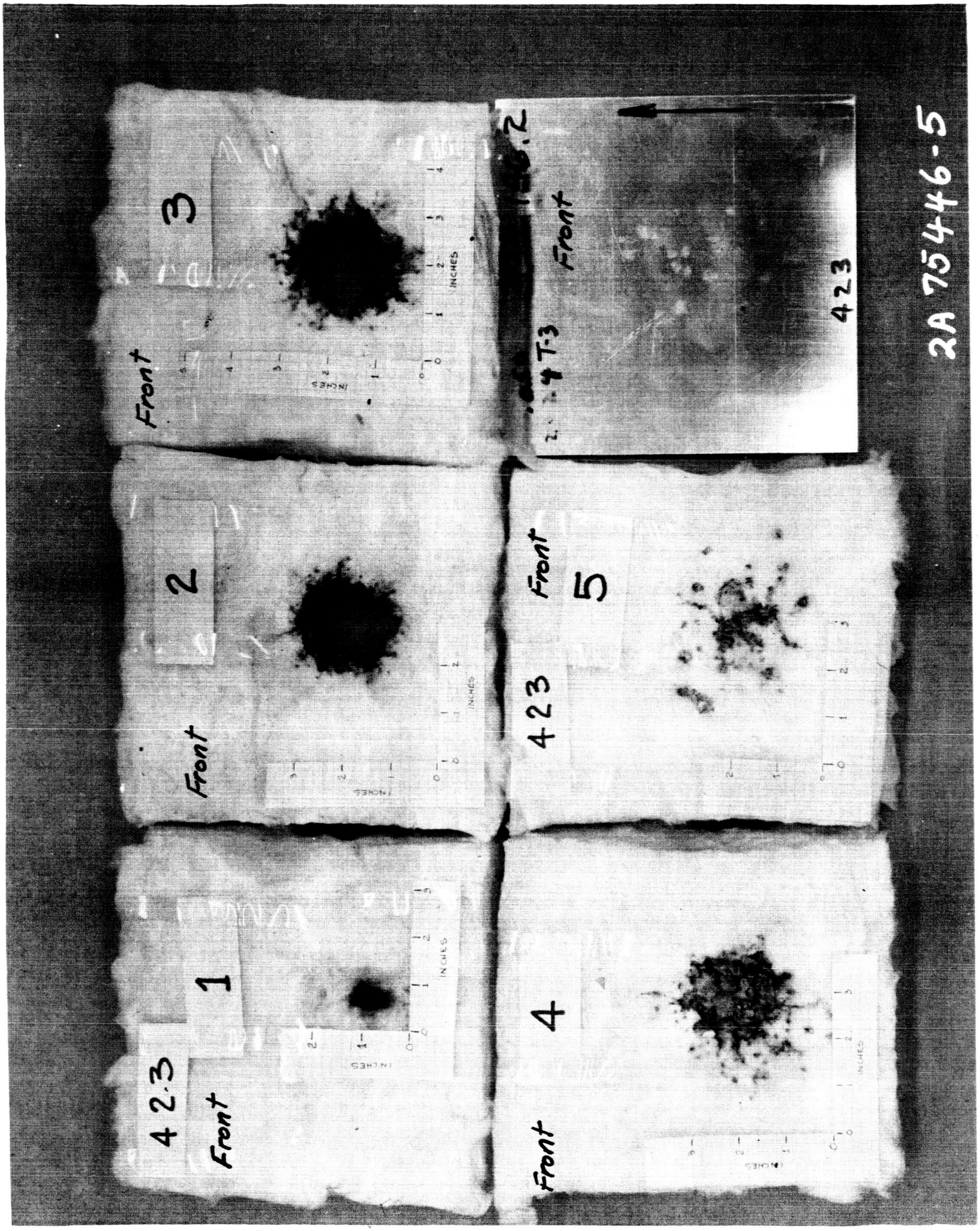
FRONT SHIELDS - CONF. 5a and 5b

FIGURE 6



FILLER MATERIAL CONFIGURATION 5a

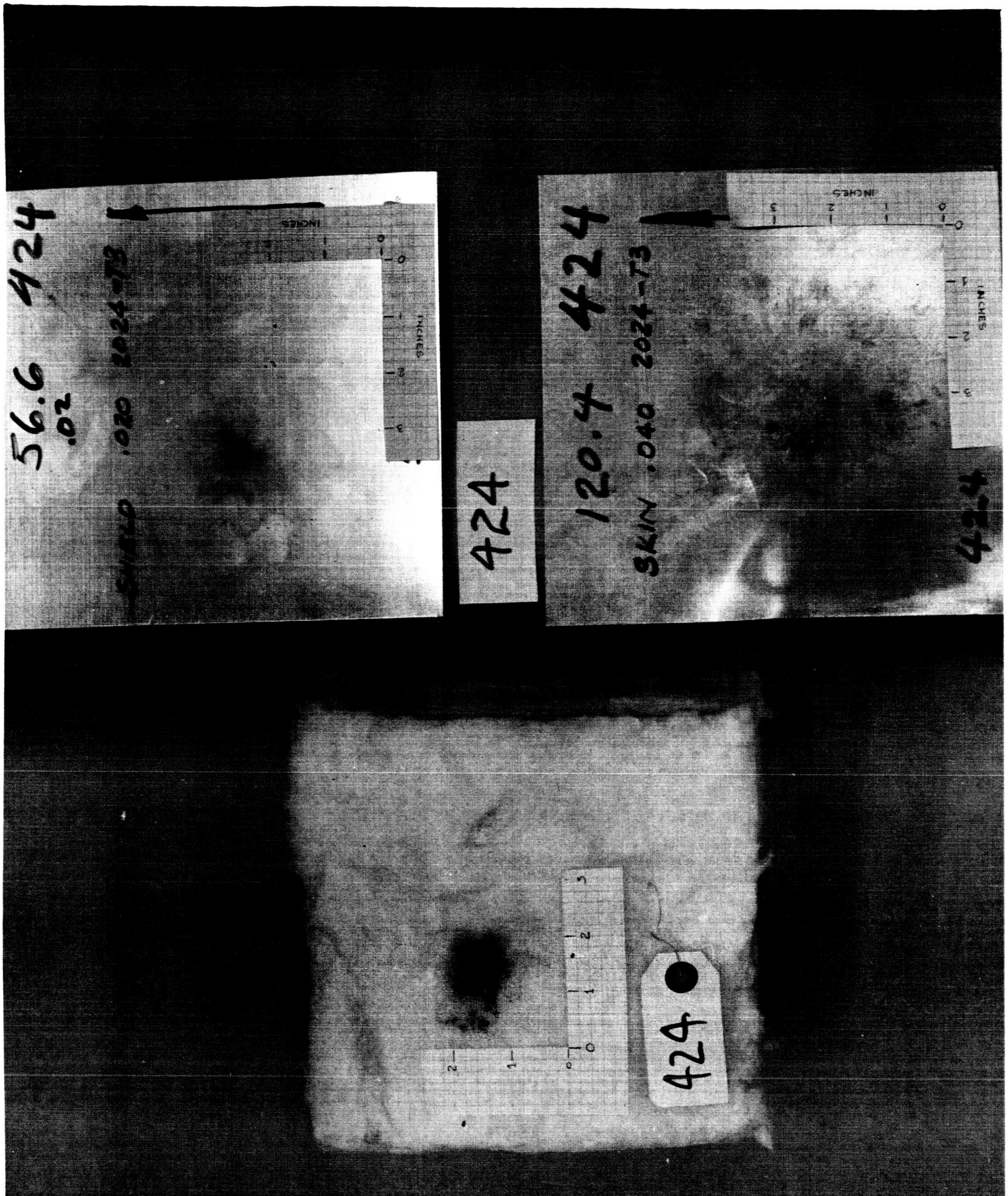
FIGURE 7



FILLER MATERIAL and .050 Al. SKIN, CONF. 5b

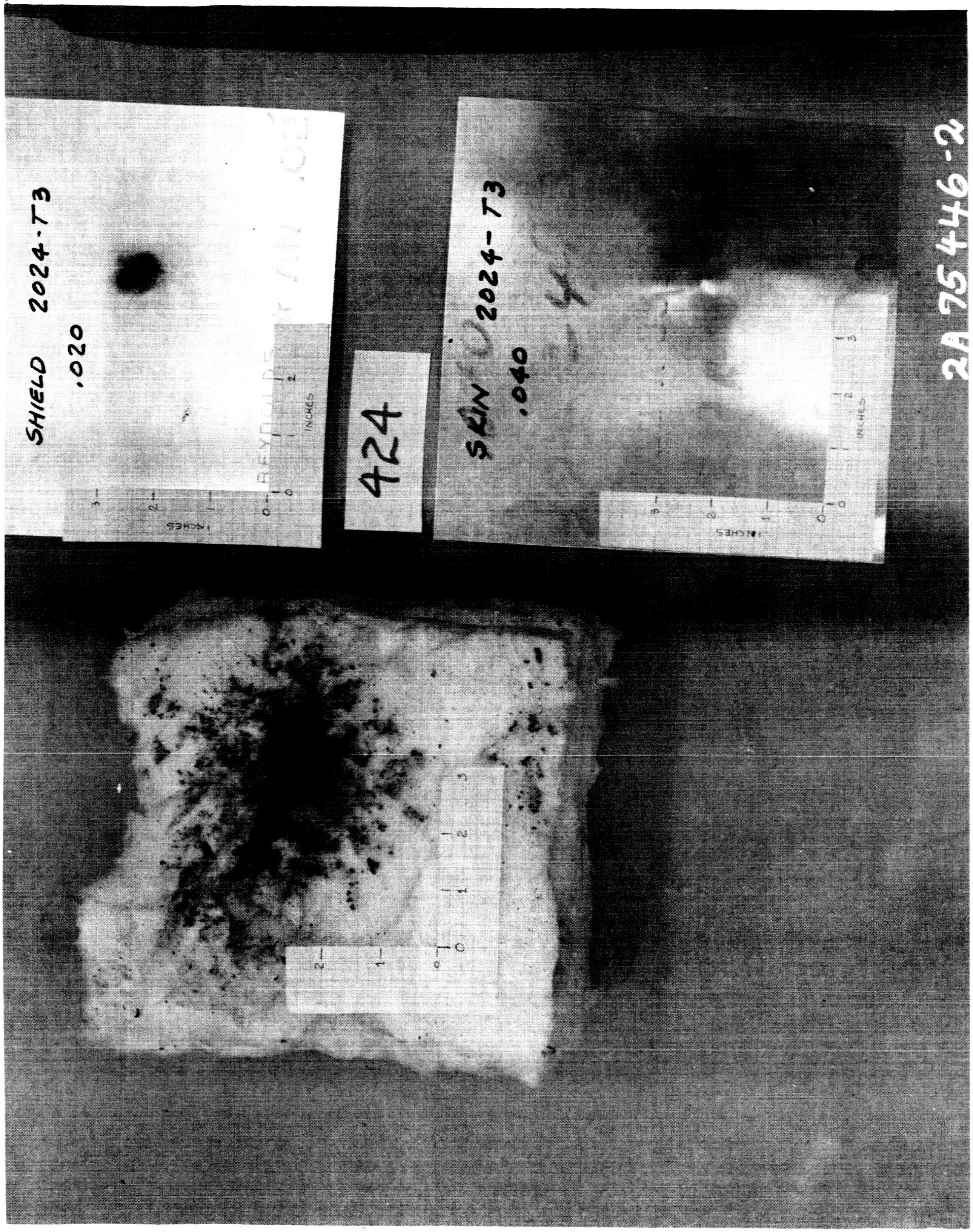
FIGURE 8

2A 73-446-3



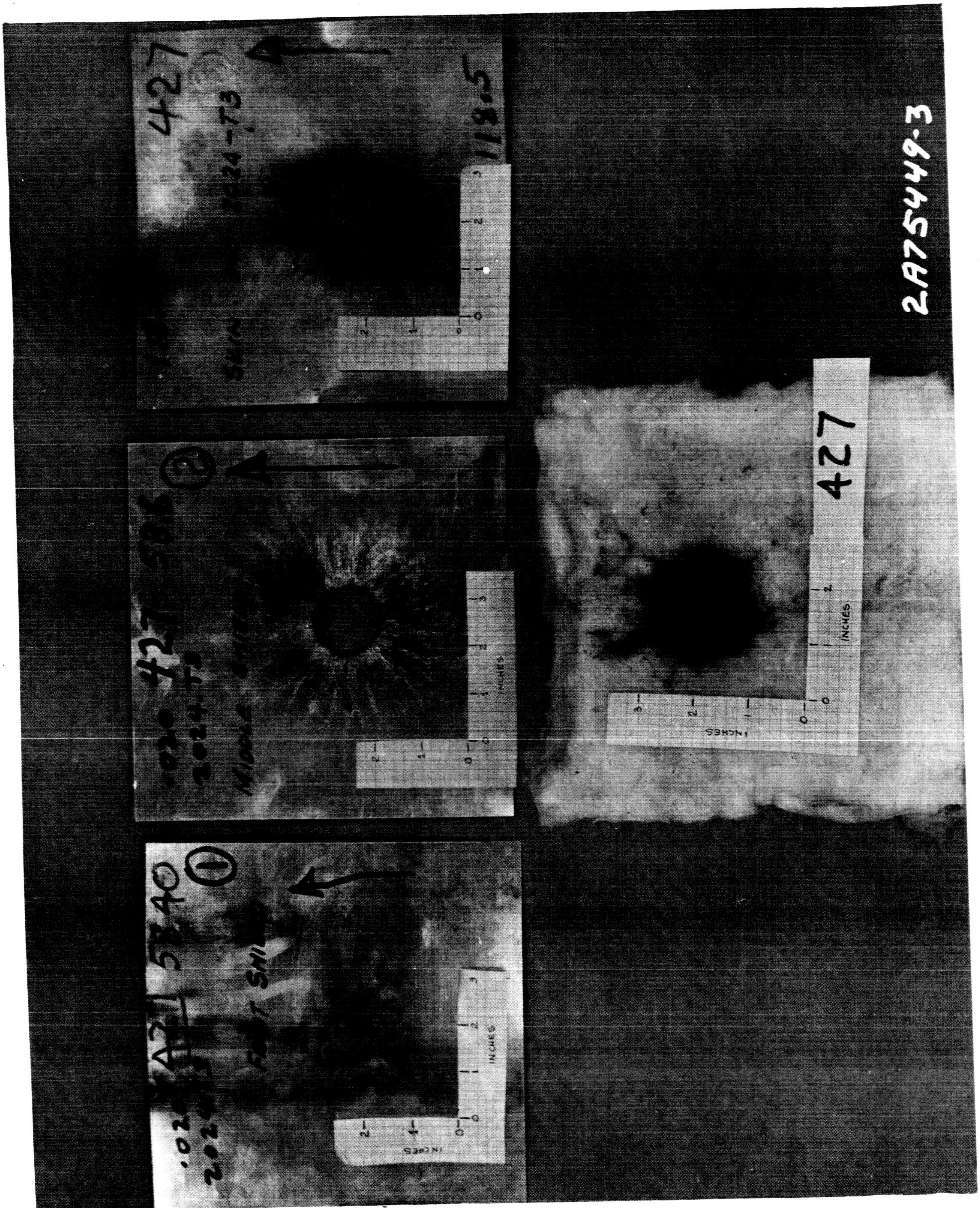
FRONT OF CONFIGURATION 5C

FIGURE 9



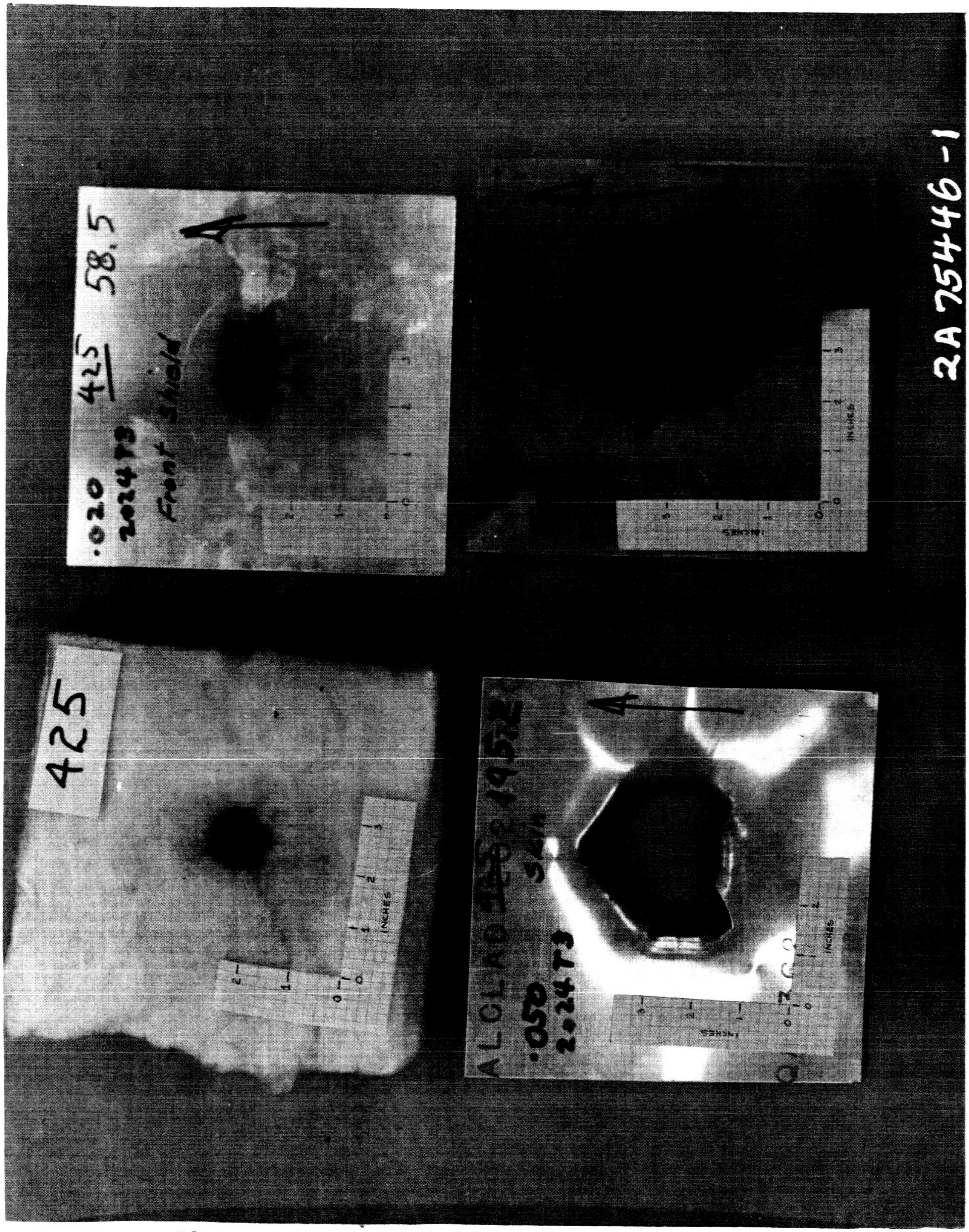
REAR VIEW OF CONFIGURATION 5c

FIGURE 10



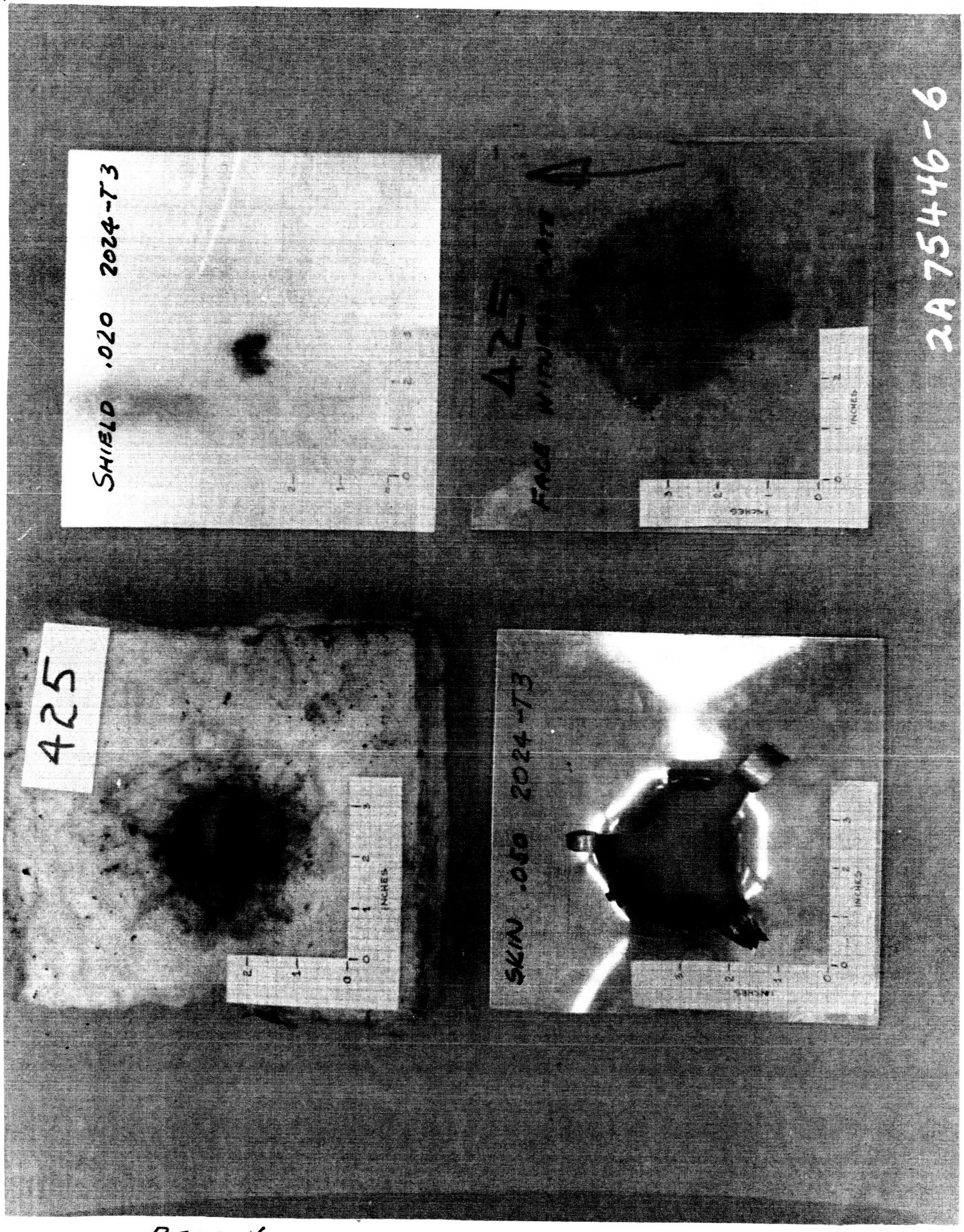
FRONT VIEW OF CONFIGURATION 5d

FIGURE 11



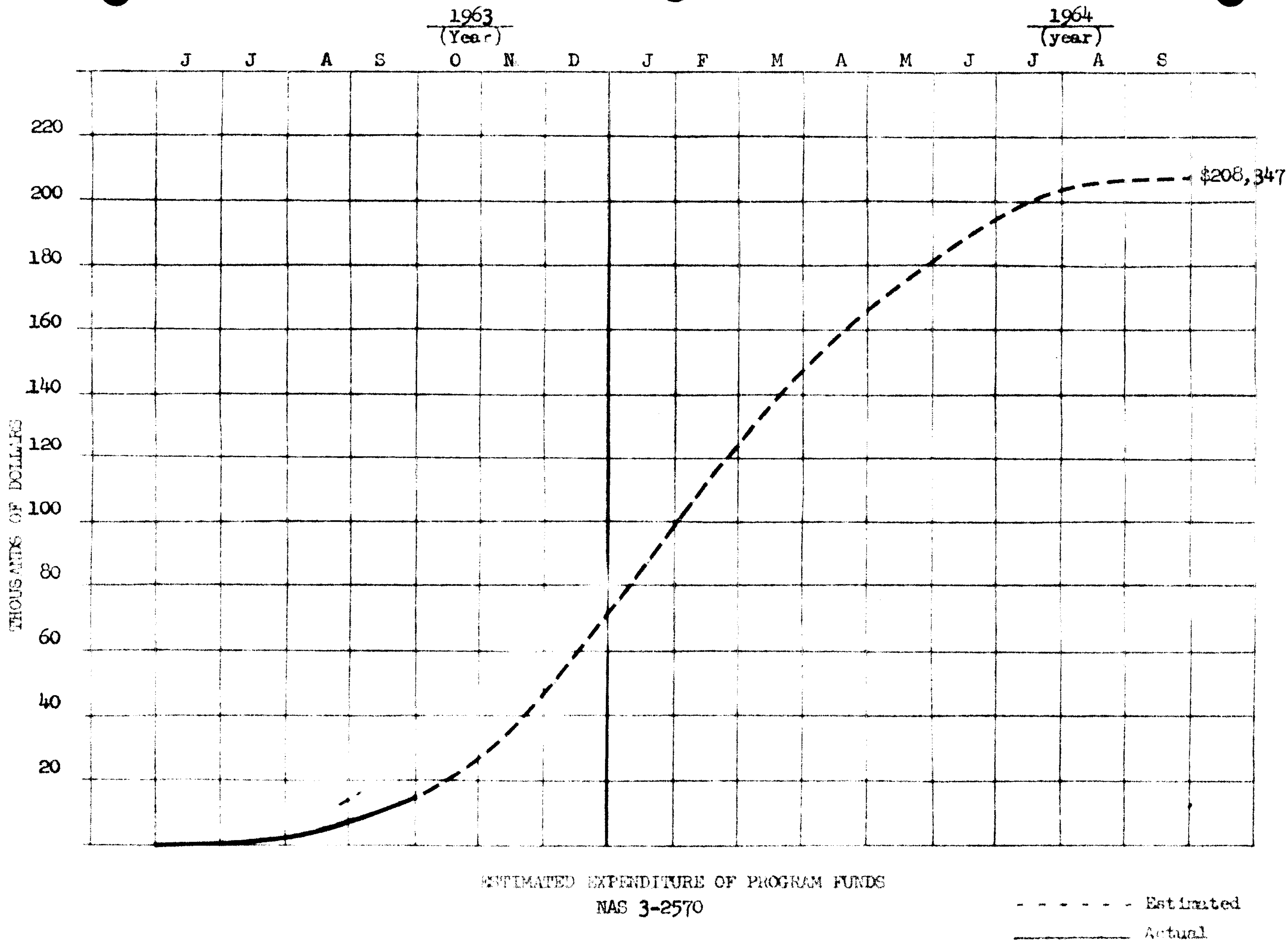
FRONT VIEW OF CONFIGURATION 5e

FIGURE 12



REAR VIEW OF CONFIGURATION 5e

FIGURE 13



ESTIMATED EXPENDITURE OF PROGRAM FUNDS
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